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# SPACE SHUTTLE RCS OXIDIZER LEAK REPAIR FOR STS-26

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## ABSTRACT

Following propellant loading of the Space Shuttle's reaction control system (RCS) for mission STS 26, an oxidizer leak was detected in the left orbital maneuvering system (OMS) pod, where the RCS is located. Subsequent investigation determined that the leak was isolated at a mechanical Dynatube fitting near the RCS nitrogen tetroxide tank. An intense effort was initiated to design, fabricate, and qualify a sealing device to stop the oxidizer leak externally so that the Space Shuttle launch could proceed. It was discovered that sealing devices called clamshells were widely used throughout the petrochemical and power generation industries to stop leaks developed in large diameter pipes which carry steam or other hazardous fluids. These clamshells are available in different diameters and strengths and are placed around the pipe at the location of the leak. A sealing compound is then injected under high pressure into the clamshell to stop the leak. This technology was scaled down and applied to the problem of stopping the leak on the Orbiter, which was on a half-inch diameter line in a nearly inaccessible location. Many obstacles had to be overcome such as determining that the sealing material would be compatible with the nitrogen tetroxide and ensuring that the clamshell would actually fit around the Dynatube fitting without interfering with other lines which were in close proximity.

The effort at the NASA Johnson Space Center included materials compatibility testing of several sealants, design of a clamshell to fit in the confined compartment, and manufacture and qualification of the flight hardware. A clamshell was successfully placed around the Dynatube fitting on the Orbiter and the oxidizer leak was terminated. Then it was decided to apply this technology further and design clamshells for other mechanical fittings onboard the Orbiter and develop sealing compounds which will be compatible with fuels such as monomethyl hydrazine (MMH). The potential exists for using this type of sealing device in numerous other applications throughout the aerospace industry.

## INTRODUCTION

Clamshell technology is used in industry to stop fluid leaks. Applications are found in the petrochemical and power generation industries. In petrochemical systems, leaks develop in lines at high pressures and temperatures, and these systems often transport toxic and corrosive materials. Also, power generation systems use comparable methods to transport fluids such as steam at high pressure and temperature. A useful sealing technology has been developed to terminate these leaks externally by enclosing the leaking line or connection in a clamshell container into which a material compatible with the leaking fluid is injected. The injected material acts as a sealant under high injection pressure. The devices are installed and checked periodically to verify that leakage has not resumed. If leakage does exist, the clamshells may be replaced or re-injected to re-stop the leak.

In industry, these clamshells are designed for applications which require large, easily assembled devices. Carbon steel is often the material used. Line sizes may be as small as 1/2 inch or as large as several feet in diameter. Typically, the clamshell is a flanged device.

Various sealant materials are used depending on the type of fluid to be encountered. Two companies that supply clamshells and sealants are Furmanite and TEAM Inc. Furmanite markets a silicon based material with graphite fiber added. The material is delivered as a stick which is inserted into a hydraulic ram gun and injected into the clamshell. TEAM markets a Teflon material which is mixed with an inert halogenated oil which is then injected. Another sealant, Chemseal 3808, is a specialty room temperature, chemically cured, silicone sealing compound, available in several viscosities. The principal criterion for selection of the sealant is its compatibility with the leaking fluid. Of concern with the Space Shuttle reaction control system (RCS) repair was the compatibility of the sealant with the nitrogen tetroxide ($N_2O_4$) propellant. Nitrogen tetroxide is the oxidizer used in the Space Shuttle RCS. The major problem with a sealant in oxidizer service is its ability to maintain integrity over an extended exposure period. A single flight of the Space Shuttle with a clamshell would require sealant compatibility for approximately 3 months. However,

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as a goal it would be desirable for the clamshell repair to last for five missions or approximately 2 years. Due to the lack of data on the compatibility of any of the sealant materials with N204, a fleet leader test program was implemented to demonstrate compatibility in real time with the Space Shuttle repair effort.

## SPACE SHUTTLE RCS OXIDIZER LEAK

The nitrogen tetroxide (N204) tank overflow line of the left pod RCS on Orbiter vehicle 103 developed an overboard leak prior to flight STS 26. The leak was detected by tank pressure decay tests indicating a loss rate of 800 standard cubic centimeters per hour of pressurant. Subsequent investigations determined that the leak was at a mechanical Dynatube fitting near the tank. The leaking mechanical fitting was located in a line, in the left orbital maneuvering system (OMS) pod, known as the RCS fill vent or overflow line. This line carries overflow propellant from the tank to a servicing panel during tank fill operations. Evidence of propellant flowing in this line assures that the tank has been filled properly. The line is a 1.27 cm (0.5) inch outside diameter, type 304L stainless steel tube with 0.12 cm (0.020) inch wall thickness, about 8 meters (26 feet) long, with numerous bends. Figure 1 shows the path of the line in the OMS pod.

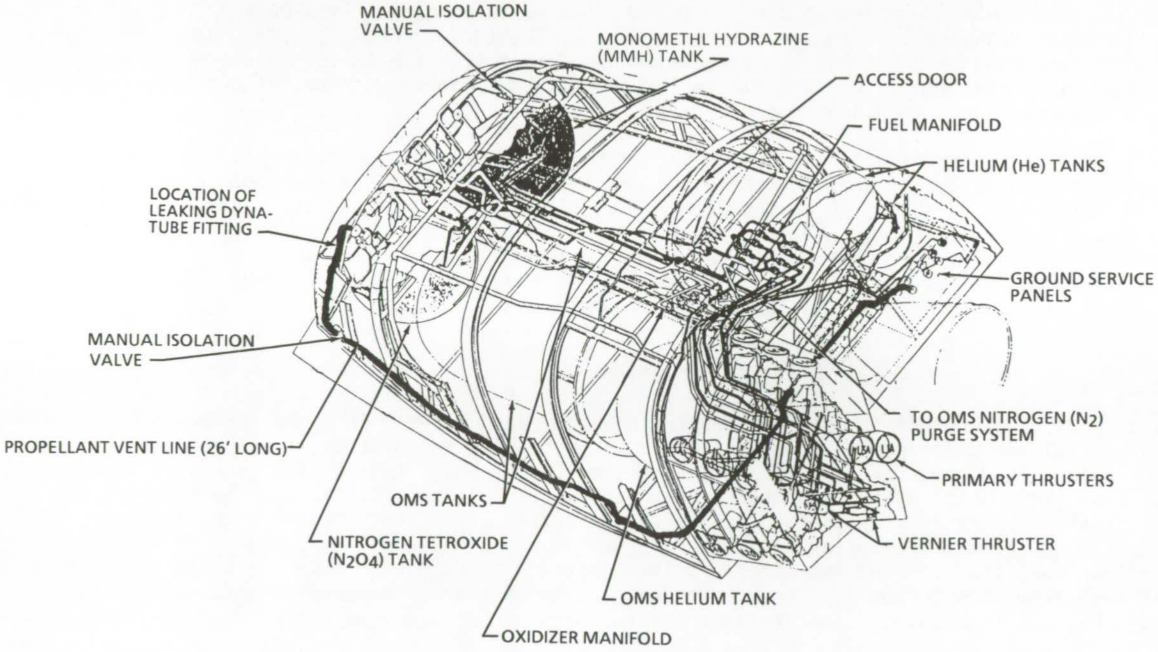

Fig. 1. Schematic of RCS Vent Line in OMS Pod.

The male half of the fitting is at the top (gas) side of the tank. As installed in the Orbiter, the female half of the fitting is always a Dynatube nut and shoulder, made by Resistoflex Corporation, but the male half can be either a Dynatube or DualSeal fitting made by Airdrome Parts Company. Both fitting halves are 17-4PH stainless steel. The actual Dynatube fitting onboard OV-103 is illustrated in fig. 2. Note that in the immediate vicinity of the fitting, the space is very congested. The assembled fitting is torqued to 100 newtons (360 inch-pounds) to 133 newtons (480 inch-pounds) and safety wired.

When the leak was detected, program managers were faced with rolling the vehicle back to the Orbiter processing facility, removing the pod, and repairing the leak - a costly launch delay. However, the vehicle couldn't be rolled back immediately because it had to remain on the pad until after the flight readiness firing occurred. This allowed some time for an on-the-pad leak repair to be attempted. Although the leak was small enough in magnitude that it posed no threat to the performance of either the RCS or the OMS, it needed to be repaired quickly because the N204 vapors leaking into the pod were known to be quite corrosive to electrical connectors, fittings, etc.

## CLAMSHELL AND CLAMP DESIGN

The Propulsion and Power Division of the NASA Johnson Space Center was tasked to support the development of a means to encapsulate the exterior of the leaking Dynatube fitting. This approach involved surrounding the fitting with a clamshell-like jacket and then injecting a sealing material inside the jacket to seal the leak. The design requirements were such that the sealant had to seal

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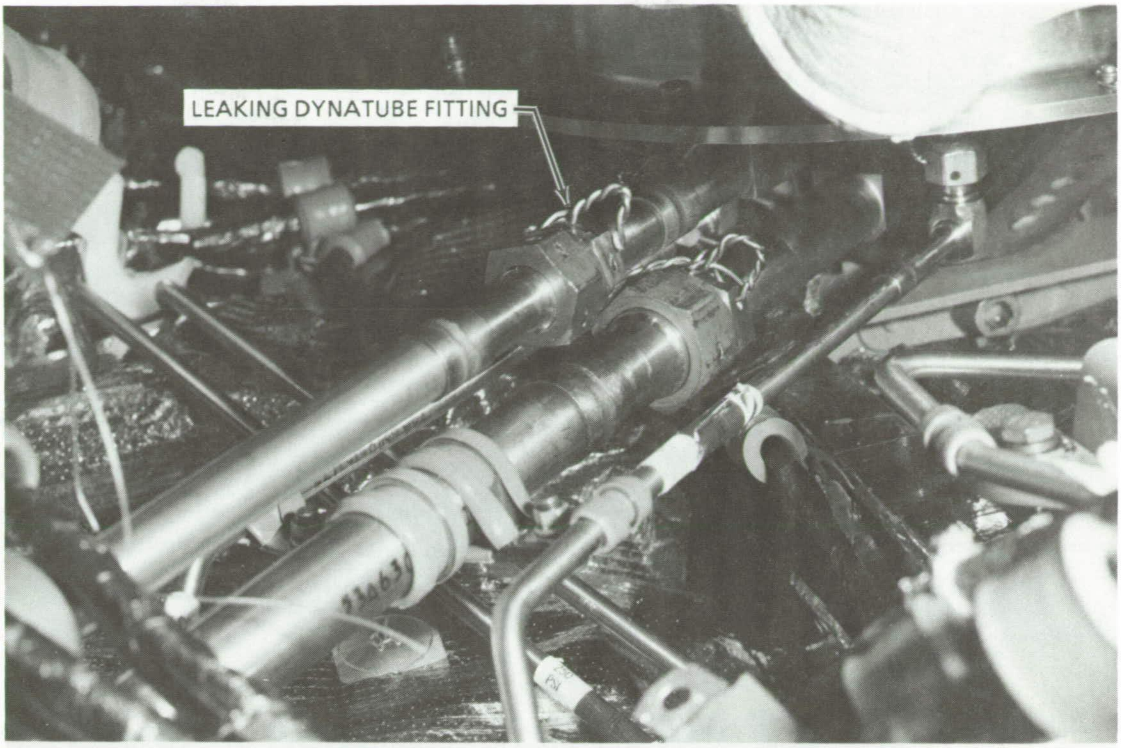

Fig. 2. Dynatube Fitting on OV-103.

against 2 068 kilonewtons/meter$^2$ (300) psia of pressure. The initial design for the clamshell concept of sealing the oxidizer leak was a simple aluminum cylinder cut in half which could be mated and then held in place by three standard hose clamps. The clamshell design gradually evolved based on feedback from a fit check performed on an identical OMS pod as well as initial test data using some of the proposed sealant materials. Bevels were added on the inside of the clamshell and the lips on the outside ends of the clamshell were removed. The final design, referred to as the JSC flight unit, was made of stainless steel and consisted of a hinged clamshell with a snap closure mechanism that allowed one-handed installation. The injection port, where the sealant pump is connected, was redundantly sealed by a screw shut-off valve and capped injection port. The JSC flight unit clamshell is shown in fig. 3.

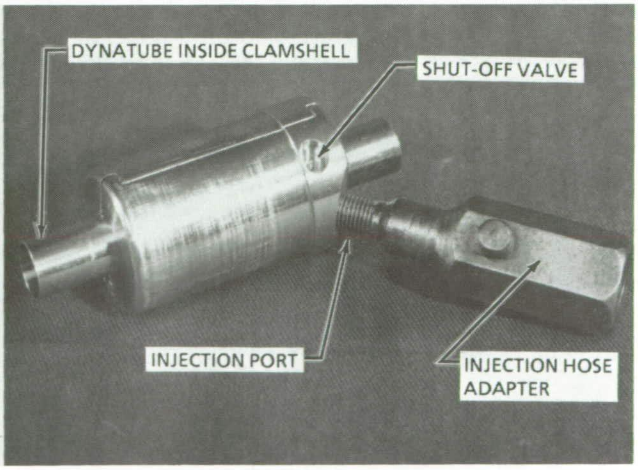

Fig. 3. Flight Design Clamshell Closed around Dynatube Fitting.

The clamp required to hold the clamshell together followed a similar design evolution. It began as standard hose clamps and progressed to a stainless steel single wide band assembled with four captured bolts made from high strength stainless steel. Figure 4 shows the flight unit clamshell assembled with the flight design clamp.

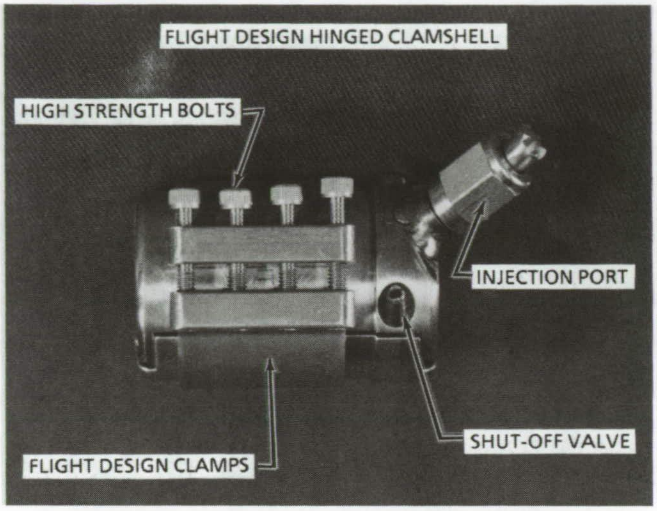

Fig. 4. Flight Design Clamshell and Clamp.

## JSC TEST PROGRAM TO QUALIFY CLAMSHELL FOR FLIGHT

An extensive test program was embarked upon to certify the clamshell, the clamp, and the sealant for the upcoming Space Shuttle flight as an interim fix until the pod could be removed for scheduled maintenance and the Dynatube replaced. The test program consisted of three equally important phases.

### SEALANT INJECTION AND LEAK STOPPAGE TESTS

Although four very different types of sealing compounds were injected into the prototype clamshells as a means of stopping a leaking Dynatube fitting, only two of these materials were serious contenders in the beginning of the test program. The two materials were Furmanite's FSC-6B and TEAM's 9CB-F10. Before injecting a sealant into a clamshell, a test article was assembled. The test article consisted of a leaking Dynatube fitting capped at one end and connected to a hand valve at the other. The Dynatube was made to leak by either scratching or nicking the sealing surface. The test article was plumbed to a gaseous helium supply. In-line between the helium supply and the test article was a pressure regulator, a pressure transducer, and a flowmeter. The schematic of the test system is shown in fig. 5. The pressure was regulated to 2 068 kilonewtons/meter$^2$ (300) psia to simulate the helium pressure in the RCS N204 tank on the Orbiter and the leak rate of the Dynatube test article was read in standard cubic centimeters per minute. Finally the sealant was injected and the flowmeter was observed closely. When the flowmeter reading dropped to zero, it indicated the sealant had stopped the leak.

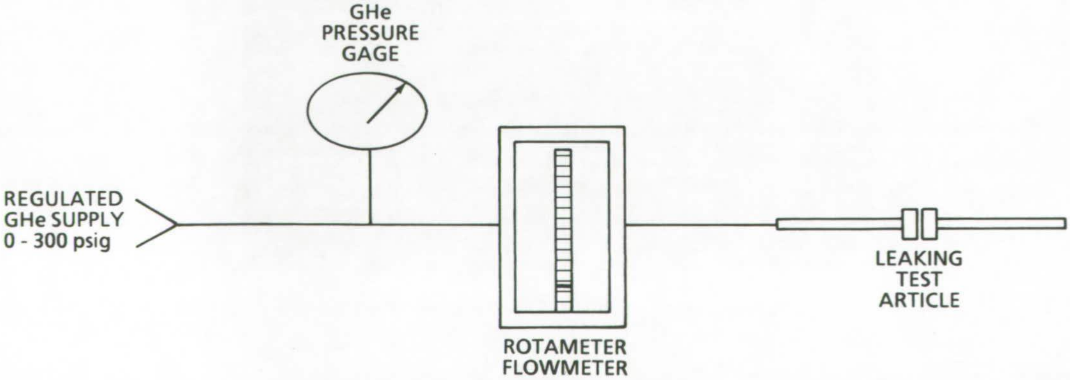

Fig. 5. Flowbench Schematic for Helium Leak Tests.

Furmanite FSC-6B is available in boxes of twelve black sticks, each approximately 1.9 cm (0.75 inch) in diameter and about 7.6 cm (3 inches) long. One stick is inserted into the loading gun which is powered by a hydraulic piston. By pumping the gun, the stick of Furmanite is extruded through a hose at the end of the gun which is connected to the inlet of the clamshell. A pressure gage on the gun indicates that the hydraulic pressure reaches a maximum of about 13,099 kilonewtons/meter$^2$ (1900 psi) after several strokes. Confirmation that the clamshell is completely full is obtained when some of the sealant is extruded out around the edges of the clamshell, when the pressure in the gun reaches a maximum, and when the flowmeter reads zero flow.

The second sealing compound to be tested was made by TEAM, Inc. and designated 9CB-F10. The 9CB is a designation for a white fluoroelastomer paste which is mixed by hand with F10 which is a powder of inert fibers. Coarse inert fibers are used for bridging while fine inert fibers are able to go down into the threads and create a tight seal. Curing is accelerated by adding an aqueous solution to the mixture. The mixture is then loaded into a pumping gun. The mixture must be injected immediately because curing is complete in approximately 30 minutes and the material is quite stiff then.

Some clamshells were injected with their sealing compound while they were pressurized with 2 068 kilonewtons/meter$^2$ (300 psia) N204 vapor as opposed to helium pressure only. This was done to see if there was any effect of the oxidizer on the sealing capability of the compounds, especially since the 9CB-F10 cured once it was inside the clamshell. However the sealants performed the same and sealed the leak and no effect of the oxidizer could be discerned.

## PROPELLANT EXPOSURE TESTING OF CLAMSHELLS

To expand the testing capability, a manifold was designed which could expose many clamshells to pressurized oxidizer vapor. The manifold was connected to the vapor (top) side of a small tank of liquid oxidizer, a regulated helium supply, a vacuum pump to evacuate the lines when necessary, and a line going to a burner to get rid of oxidizer fumes safely when needed. The schematic of the test manifold is shown in fig. 6. On the manifold, the test articles are placed in a stationary upright position with clear Teflon bags around them to capture any fumes that might leak out. If an oxidizer leak occurred, it was easily detected by the presence of brown fumes in the bag.

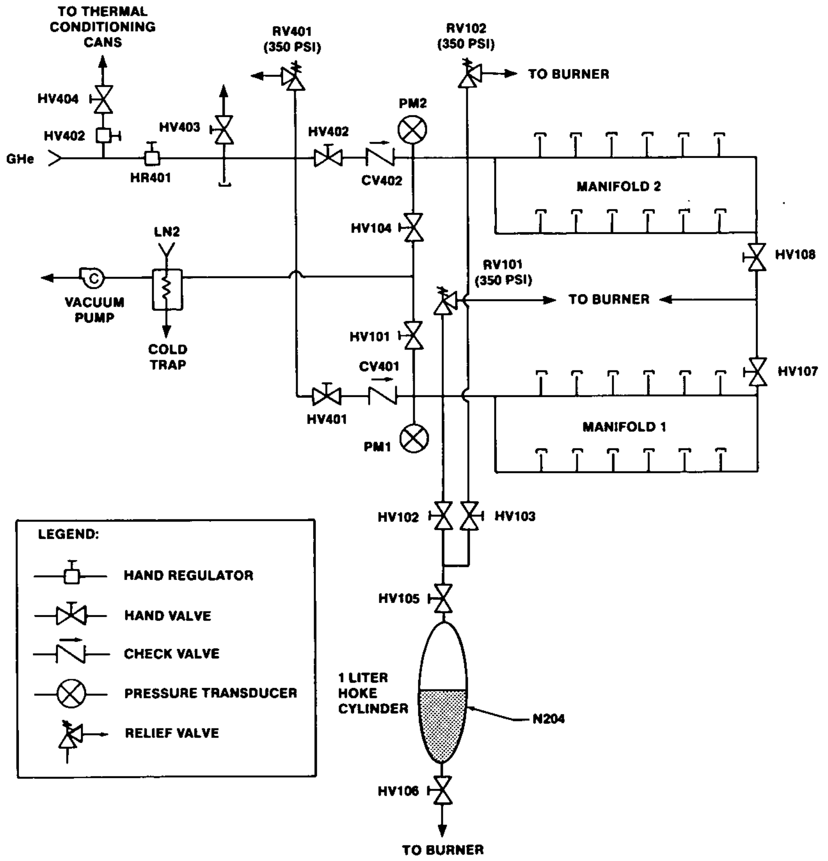

Fig. 6. Oxidizer Manifold Schematic.

Eight clamshells were filled with the Furmanite compound. Two of the Furmanite clamshells were exposed to liquid N2O4. This was accomplished by filling the test article with liquid oxidizer so that the liquid covered the Dynatube fitting. Then the test article was placed back onto the manifold, but instead of standing upright, it was hung over the edge of the table so that the liquid would stay in the test article. This was a worst case test because the fitting on the Orbiter would only see liquid oxidizer during periods of zero gravity, typically no more than 7 days. Liquid propellant is much more corrosive than the N2O4 vapors.

Seven clamshells were filled with TEAM's 9CB-F10. One of the seven clamshells was exposed to liquid N2O4. The success of the seal using this compound was very sensitive to the exact mixing process, the cure time, the pump pressure, and the number of strokes of the injection gun.

## THERMAL CYCLE TESTS OF CLAMSHELLS

Since the clamshell would be located in the Orbiter OMS pod in a very inaccessible place, Space Shuttle program managers decided the clamshell might have to remain in place for as long as five missions before a scheduled removal and maintenance of the pod. This meant that for each flight, the clamshell would undergo a thermal cycle. When the Space Shuttle lands at Edwards Air Force Base in California, the clamshell might reach a soak out temperature of 54 °C (130 °F). While the Space Shuttle is being ferried back to Kennedy Space Center by the 747 carrier aircraft, the clamshell might cool down to -9 °C (15 °F). To simulate this scenario, two flight design clamshells containing the two candidate sealants, Furmanite FSC-6B and TEAM 9CB-F10, underwent five thermal cycles between -9 °C (15 °F) and 54 °C (130 °F) with a two hour soak at each temperature. For a worst case scenario, the last thermal cycle took the temperature up to 66 °C (150 °F) instead of 54 °C (130 °F). The clamshells were pressurized with helium only for this test. A thermal bath of a water-glycol mixture was used to change the temperatures of the clamshells. Helium leakage was monitored continuously throughout the test. Neither clamshell showed any extrusion of sealant during any portion of the test. After all the thermal cycles were completed, the Furmanite clamshell was leaking at $3.5 \times 10^{-5}$ scc/sec and the TEAM clamshell was leaking at $1.2 \times 10^{-5}$ scc/sec. The TEAM clamshell showed virtually no leakage through the first three cycles while the Furmanite clamshell began to leak after the first thermal cycle.

Based on the initial findings at this point in the test program, Furmanite was chosen as the sealant for the clamshell repair effort on the Orbiter OMS pod. However, since it was planned for the clamshell to remain on the vehicle for a period of two years or even more, it was decided to create a database using test data on clamshells and potential sealants for future spacecraft applications.

## CURRENT AND FUTURE SEALANTS TESTING

Testing is continuing at NASA JSC to characterize the sealing performance of Furmanite FSC-6B, TEAM 9CB-F10, and Chemseal 3808 kept under exposure to nitrogen tetroxide. The purpose of this program is not to do a detailed analysis of the current clamshell design; rather it is a materials comparison for the 3 sealants over a simulated five mission life. The test program consists of 10 Furmanite, 9 TEAM, and 9 Chemseal filled clamshells for a total of 28 test articles. Of these, two clamshells of each sealant material are used for a 5 mission thermal cycle simulation test. The Furmanite and TEAM test articles use the flight type JSC hinged clamshell while the Chemseal test articles use industry type gasket clamshells. The other 22 clamshells will be exposed to the propellant in a static temperature environment. For these Furmanite and TEAM test articles, development type aluminum clamshells are used, and for the Chemseal test articles, the same clamshell design as for the thermal cycle units are used.

All test articles are exposed to N2O4/helium vapor at 2 068 kilonewtons/meter$^2$ (300 psia). On roughly 4-5 month intervals the six "thermal cycle" clamshells are placed in a thermal bath and alternately heated and cooled to a defined thermal profile. When the clamshells are thermally cycled, leak rates fluctuate, possibly due to the difference in thermal expansion between the metal clamshell and the sealant.

Periodically one of each of the static exposure clamshells will be removed and disassembled. The effect of static propellant exposure over time will be determined from these 22 test articles. The sealants will be analyzed to determine general degradation of physical properties. At the end of the five mission thermal cycle test, the other six test articles will also be disassembled for analysis.

The thermal profile consists of raising the test articles from ambient temperature to 38 °C (100 °F) for 5 hours, then cooled to 4 °C (40 °F) for 5 hours, then warmed to 54 °C (130 °F) for 4 hours, and finally cooled to -9 °C (15 °F) for 10 minutes. The first thermal cycle of the test program was initiated on March 15, 1989. The estimated completion date for the five mission simulation is September 1990.

Preliminary results from the first thermal cycle test showed that all test articles performed well at all temperatures. The Furmanite clamshells showed the greatest helium leak rates at ambient temperature, on the order of $1 \times 10^{-4}$ scc/sec. The TEAM test articles maintained leak rates below $8 \times 10^{-5}$ scc/sec at ambient temperature and the Chemseal clamshells maintained leak rates below $7 \times 10^{-7}$ scc/sec.

In addition to the work described above for oxidizer service, NASA JSC is interested in developing clamshell technology for fuel systems. The Space Shuttle orbital maneuvering system (OMS) and RCS propulsion systems utilize monomethylhydrazine (MMH) with nitrogen tetroxide as bipropellants. The auxilary power unit (APU) uses monopropellant hydrazine ($N2H4$) to drive a hot gas generator. Components in these systems are connected with the same type of mechanical fitting as the RCS oxidizer line that leaked. Future problem resolution in one of the MMH or $N2H4$ systems may employ the same clamshell approach. These sealants, along with other candidates, will be assessed for their material compatibility in these fuel environments.

In conclusion, the oxidizer leak that delayed the launch of the STS 26 return-to-flight was successfully resolved by application of industry clamshell technology to the Space Shuttle vehicle and environment. Work is continuing to develop a database of several sealant materials for future needs. The work performed in this area has applications to other aerospace programs as well.